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ABSTRACT

This paper presents an exposition of the mathematics of native peoples of North America related to the Western mathematics traditionally studied at the elementary through college level. This ethnomathematical review is made not only to allow instructors of Native American students to include in the school curriculum relevant mathematics developed by Indian people, but also to offer all students a fuller understanding of the universal nature and power of mathematics. Primary and secondary sources of Indian and Western mathematics were surveyed, summarized, analyzed, and synthesized. Sources of curriculum materials for inclusion of Native American approaches to various mathematical topics are offered throughout. The review concludes with a discussion of the implications for teaching and learning mathematics. (Contains 28 references.) (Author/ASK)

Indian Mathematics: An Ethnomathematical Review

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Running Head: INDIAN MATHEMATICS

Abstract

This paper presents an exposition of the mathematics of native peoples of North America related to the Western mathematics traditionally studied at the elementary through college level. This ethnomathematical review is made not only to allow instructors of Native American students to include in the school curriculum relevant mathematics developed by Indian people, but also to offer all students a fuller understanding of the universal nature and power of mathematics. Primary and secondary sources of Indian and Western mathematics were surveyed, summarized, analyzed and synthesized. Sources of curriculum materials for inclusion of Native American approaches to various mathematical topics are offered throughout. The review concludes with a discussion of the implications for teaching and learning mathematics.

Mathematics is universal in nature, cutting across time and space (Burton, 1985; Eves, 1990). In a traditional mathematics curriculum in the United States, whether at the elementary, secondary, or college level, scattered reference usually is made to the individuals or cultures which contributed to the mix we call "modern mathematics" (National Council of Teachers of Mathematics, 1989; National Research Council, 1989, 1990). Mathematics in schools in the United States, although focussed on Western European contributions, still tends to note knowledge from other peoples: Greece, Egypt, India, China. Even the Mayans and Aztecs often are recognized for their mathematics-based engineering and astronomical prowess, and calendars (Closs, 1986a; Payne & Closs, 1986; Vinette, 1986).

Infrequently mentioned in most mathematics instructional settings in the U.S. is a parallel, rich system of mathematics developed and used by indigenous people of North America, often referred to as American Indians or more recently as Native Americans (Closs, 1986a; Nelson-Barber & Trumbull-Estrin, 1995; Peat, 1994). This lack of acknowledgement, it is suggested, is not only detrimental to the instruction of today's Indian students (Nelson-Barber & Trumbull-Estrin, 1995), but also, the authors would suggest, this omission denies all students a fuller appreciation of the universal nature and power of mathematics.

This paper presents an ethnomathematical exposition of selected topics from the mathematics developed and utilized by peoples in various North American Indian tribes. It shall report the motivation behind the development of that mathematics by those peoples,

and offer a rationale and methods for the inclusion of such non-traditional knowledge into public school classrooms.

Sacred Mathematics: The Role of Mathematics in Indian Culture

The history of mathematics in American schools mentions the mystical, secret societies dedicated to mathematics, and the sometimes supernatural sense some had about mathematics (Burton, 1985; Eves, 1990; Peat, 1994). For example, the Pythagoreans pledged an oath of secrecy about their discoveries. Masons embedded numerical and geometric symbols while building medieval cathedrals. Renaissance artists sought to connect nature and mathematics in their development of visual perspective. Kepler's discovery of the similarity of the mathematical commonality between musical intervals and within the orbits of the planets of the solar system suggested to his contempories a "music of the spheres."

So, too, has mathematics had a mystical, spiritual element for American Indians (Peat, 1994). Mathematics was considered a living form, an expression of energy and spirit. More specifically, in contrast to the dehumanizing portrayal of number in Western culture ("Being treated as if I were just a number instead of a human being."), native peoples in North America considered number a source of power. Indian tribes tended to believe that in number they were able to maintain balance and harmony in a world of constant change. In fact, numbers were considered manifestations of things, as we shall later discuss.

Likewise, geometry is considered a source of power and strength by American Indians (Vinette, 1986). Whether as demonstrated in petroglyphs throughout North

America, in the Medicine Wheels of the Great Plains (Conn,1985; Forest Service, 1997; Geist, 1993; Leerhsen, 1991; Nikiforuk, 1992), or the beading and weaving of daily and ceremonial wear (Bradley, 1992; Conn, 1985; Peat, 1994; Stump, 1972), geometry finds expression in Native American cultures in ways that transcend the utilitarian or artistic: geometry takes on a spiritual and religious component.

Just as the Greeks sought to find unity and harmony between number and geometry (Toeplitz, 1956), so too did American Indians seek balance and oneness in components of mathematics. What follows is a discussion of representative number and number systems, together with general conceptualizations of Indian systems of geometry, followed by suggested connections and unity indigenous peoples saw between these two mathematical disciplines.

Wheel of Power: American Indian Numeration and Geometry

Number and Numeration Systems

Native Americans tended to see numbers in quite a different way than Westerners (Closs, 1986a; Nelson-Barber & Trumbull-Estrin, 1995; Peat, 1994). Numbers were not abstract or remote, but rather alive and real, beings which help explain the universe. As mentioned earlier, by the use of number, American Indians sought to maintain balance and harmony in an ever changing world.

For example, among the Native People of Turtle Island the number four commonly represented a state of balance and harmony (the static), as well as movement of spiritual forces (the dynamic) (Peat, 1994); that is, the number four represented the four directions

of the compass (fixed), but also represented the four winds (flux). Four was manifested in a number of Indian devices, such as the medicine wheel and the hoop.

An example of the poetic and reality-based names for numbers used by the Zuni Indians of the Southwest is given in Table 1. These number words and their literal meanings suggest the vivid imagery and practicality of Native American numerals and number systems.

Insert Table 1 about here.

Medicine wheels.

Medicine wheels are collections of stones, bones and other materials constructed by indigenous peoples in the western Great Plains of Canada and the United States (Geist, 1993; Nikiforuk, 1992). These structures tend to be in the shape of a circle or concentric circles with adjacent or contiguous cairns. These figures are the source of much legend and uncertainty, possibly sites of religious, cultural or astronomical observations (Leerhsen, 1991; Nikiforuk, 1992). Whatever their use, mathematical scientific precision in number and geometry can be seen in their construction, and demonstrate the Native American believe in the circle as the ideal form, having no beginning or end, and reflecting the eternal continuity of life (Conn, 1985).

A classic example of this precision is the Big Horn Medicine Wheel located in the Big Horn Basin of Wyoming, as shown in Figure 1 (Forest Service, 1997). Thought to have been constructed between 1200 and 1700 A.D., it is approximately 245 feet in

circumference with 28 spokes radiating from its center to the outer rim. These 28 spokes not only are thought to represent the 28 ribs of the bison, but also a number of them are placed along the lines of important astronomical events in the lives of the native people (for example, the beginning of seasons, the traditional buffalo jumps). These important spokes are marked by cairns at their ends, repositories of artifacts thought to be offerings or talismans of prayer or thanksgiving.

Insert Figure 1 about here.

The hoop.

The hoop was not only an abstraction of four, but also a representation of number as process. In Indian dance, the hoop is constantly in motion with each of the four directions having a place on the hoop. But the constant motion of the hoop symbolizes how each direction, each of the four winds, yields to the other. Each direction is part of arrival and departure, yielding one to the other, a constant motion of birth, death and rebirth.

Basis and number.

American Indian symbolic representation of numbers can be found across North American, often in the form of inscriptions on rocks or "petroglyphs" (Closs, 1986b). These markings in the form of symbols, holes, or tallies, allow us to deduce the bases used in their number systems, often centered around hunting cycles, the seasons, the lunar calendar or other elements of daily life.

Generally, as in other cultures around the world, the basis for number systems was decimal (base 10), but this was not always the case (Closs, 1986). Groups which used base 10 included the Sioux, Iroquois and Salish; however, among Inuit (Eskimo) and many California peoples, base 20 predominated. In addition, at times secondary groupings were used to generate 5-20 or 10-10 blended systems of counting. In fact, some Indians used a different natural basis (such as the binary) or no basis at all.

A clever example of a Native American numeration system comes from the Mayans of northern Central America as outlined in Figure 2. Although it was thought to be based originally on 5, it later became clear that it actually also had a base 20 component--an example of a 5-20 blended system. Each dot represents a 1, each line represents a 5, and the symbol for 0 looks like a turtle shell. As shown in Figure 2, the biggest number in any one place was 19, with greater numbers written in terms of base 20, with numbers written in the vertical form.

Insert Figure 2 about here.

The sources for the names of numbers can be quite inventive and poetic, reflecting once again the life-related nature of Indian mathematics (Eells, 1913). The word for "1" is sometimes related to the word for "I." For "2", the root is often found in a word for pairs or separation (Omaha, <u>nomba</u>, "hands", or Apache, <u>naki</u>, "feet"). Sometimes number words were formed using arithmetic operations , such as addition (Nootkan for 15, <u>hayo ogish socha</u>, from <u>hayo</u>, 10, and <u>socha</u>, 5), subtraction (Crow for 8, <u>nupa-pik</u>, from <u>upa</u>, 2,

and pirake, 10), or multiplication (Kutchin for 6, neckh-kiethei, from nackhai, 2, and kiethei, 3) (Closs, 1986a; Folan, 1986). In these methods, one is reminded of European languages, such as German, which also used arithmetic operations to generate number words (fuenfzehn, 15, from zehn, 10, and fuenf, 5; or hundertvierundzwanzig, 124, from hundert, 100, zwanzig, 20, and vier, 4).

An extremely visual and poetic example of Indian number can be found in the Inuit method of counting to 100: two hands are 10, add one foot for 15, add the other foot for 20 (which is one person). Five people make 100--as did a picture of a bundle of fur, since skins were bundled in groups of 100. A visual representation of this set of Inuit counting numerals is given in Figure 3.

Insert Figure 3 about here.

Whether calling the winds to mind or picturing bounty, American Indians saw number as an expression of the life around them. As has been shown, even the counting process harkens to the center of Indian life, the hunt.

Geometry

A useful guideline in appreciating and investigating American Indian mathematics is that, as seen in the previous section on numeration, mathematical ideas are very context sensitive (Denny, 1986); that is, while Western culture generally used mathematics to shape the environment into a more "human-friendly" form, Indian mathematics tended to

be shaped by the environment--an "earth-friendly" mathematics. This clearly can be seen in Native American geometry.

Shape was a fundamental concern in the hunter and gatherer societies of North America. Where a strictly agarian society would be concerned with accurate means to measure the earth (literally, "geometry"), Indian groups were interested in descriptive categories that reflected their daily experience.

An example of this is the shape category "round" as given in Table 2. This category included such diverse objects as a circular coin, a slightly flattened tomato, a vertically elongated apple, or an irregular potato. The Ojibway had a term noomin, meaning round and oblong, which could be used to describe objects like a cucumber, a long potato, or an egg. The rounder an object became, the more often the intensifier "wewemi-" would be added by the Ojibway, as in wewemi-noonimaa ("it is shaped regularly round and oblong"). This categorization was quite subjective, with the boundary between round and angular left to the convention of the group.

Insert Table 2 about here.

Nearly round objects would simply be called "waawiye-" (as in, "waawaye-aa", "it is round"). Thus an object which seemed to have one focus would be in the category waawiye-, while an object with two foci (as an ellipse) would be in the category noonim-.

Another example of this use of geometrical categorization to describe the world is in dimensionality as shown in Table 3. One-, two- and three-dimensions are divided into

vague categories determined by length, width, and thickness. One-dimensional objects, like a stick, have large length, small width and thickness. (Note that in Western geometry a line has positive length, and no width or depth.) A two-dimensional object, such as an animal skin, has large length and width, but small thickness. (Noting again, the plane has positive length and width and no depth.) A three-dimensional object such as an acorn has length, width and depth. (A geometric solid has positive values for length, width and depth.)

Insert Table 3 about here.

Indian societies utilized a myriad of categories, far more than those used in Western geometry (Denny, 1986). The categories often were the result of the compounding of attributes. It also should be noted that cultures invented new terms to accommodate new shapes brought to North America by Europeans. For example, a box in Ojibway was "gakakadeyaa" or "It is repeatedly right-angled." A glass dish with straight handles on two sides was called "niizhing zhash aweyaa," or "It is non right-angled twice."

Finally, as shown in Figure 4 Native American geometry most clearly expresses itself in arts and crafts (Conn,1985; Stump, 1972). The geometry used is closely related to what we would consider transformational geometry, with its characteristic symmetry, translations, rotations and glides (Bradley, 1992; Lott & Burke, 1998; Taylor, et al., 1991).

Insert Figure 4 about here.

As stated earlier, the vector of knowledge for Indian geometry tended to be from Nature to mathematics; the vector for Western geometry tended to be from mathematics to Nature with the intention of altering Nature. Native American geometry tends to be literary, philosophical and artistic; Western geometry tends toward the practical, scientific and engineered.

Other Topics from American Indian Mathematics

Measurement.

In hunting and gathering societies such as those of North American Indians, measurements are frequently made, but in a different way than in industrial societies. In keeping with the subjective, world-based nature of other areas of their mathematics, Indian measurement tends to be sensitive to real-world sources (Denny, 1986).

For example, in building a structure the architect might choose his hand or arm as a standard of measurement. The size of the entire structure, together with the individual room, would be determined by individual judgment ("eyeballing") rather than some fixed overall standard. Since most such projects were completed by one individual or his immediate family, the objective standardization required in an industrialized society were not needed. The subjective, individualized, localized standard was enough.

The type of measurement required by Native Americans was different than those of Western societies as well. Measurement tended to be limited to linear distance, volume and time. Area, weight, temperature and monetary value tended not to be quantified.

Linear units provide an illustrative sample of Indian unit generation. The Inuit and Ojibway systems of measurement for kayak and canoe building, respectively, were similar in nature, both based on body parts (as in the English system). Since there was great variety between individuals, these units can best be understood as families of units rather than as absolute standard measures. These units included: finger widths, hand widths, hand spans, forearm lengths, single arm spans and double arm spans.

While these measurement procedures may seem crude and imprecise to a Westerner, they were completely functional and adequate for the societies which used them in North America. In addition, they are methodologically consistent with some Western systems, such as the English measurement system (see Wheeler, 1995, for a fuller discussion of these "body-based" origins).

Probability and chance.

As mentioned earlier, Native American people saw the world in constant flux (Peat, 1994; Ryan, 1999). After plans were made, something often would come along (sometimes called the "Trickster") to put lives on a different path.

Native people did not regret, but celebrated this constant change in a variety of ways. Gambling, for example, was an important part of their cultural lives. But gambling was not entertainment or a get rich quick scheme as it is in our society, but a sacred instructive ceremony to acknowledge the random order in the universe and to try to better discern that order.

The Mohawks had the Peach Stone Game. The Mic Maqs had the Waltestaqaney Game. The Flatheads still have stick games. Northwestern Indians have Potlach Games.

Each game demonstates knowledge of the laws of probability which the "tally keeper" utilizes to compute the odds of outcomes and record results.

Chaos theory and fractal geometry.

In order not to give the impression in this article that American Indian mathematics was limited to elementary mathematical domains, it should be noted that elements of higher, contemporary mathematics also found expression in Native cultures. Example of this are the topics of chaos theory and fractal geometry.

Chaos theory investigates how probability, chance and randomness can help explain phenomena in the world (Bedford, 1998; Brown, 1996; Burke, 1997). Whereas an Aristotelean or Newtonian worldview would tend to be more deterministic with orderly, predictable actions and reactions, chaos theory discribes a universe far from fixed (Brown, 1996). Processes based in large part on chance, such as the weather, geology and biology can play critical in everyday outcomes of one's life. An exaggerated anecdote which is often given as an example of this type of interaction is the effect of the flapping of the wings of an Amazonian butterfly on a hurricane in Texas. First finding expression in the 17th and 19th centuries, chaos theory has only recently moved into the forefront of modern mathematical explorations in Western mathematics, but is consistent with the interactive world view of Indian cultures.

Fractal geometry, a tool for describing seemingly chaotic systems such as clouds, coastlines and snowflakes, is related to chaos theory (Bedford, 1988; Pietgen, et al., 1992). Derived from the same intellectual foundation and philosophy as chaos theory, fractal geometry is a means to relate order and disorder, to bring harmony to seemingly

disharmonious processes. Practical discussions of fractal geometry, its relation to Native American traditions, and related activities for the classroom, can be found in Jurgens, et al. (1990), Lott & Burke (1998), and Pietgen, et al. (1992),.

Chaos theory and the related domain of fractal geometry are consistent with the belief of many American Indian cultures that harmony and stability can result from chance and disorder (Peat, 1994). A basic element of their worldview was that order grew out of chance and change. As Peat (1994) noted, the Iroquois saw order and chaos as two brothers, each of whom create the opposite of the other. When one creates something, the other makes the opposite. If one makes "up," the other will make "down." One would not hope to have one brother without the other, since one brother's creation could not exist without the other's (another example, no day without night).

It is interesting and important to note that modern appreciation of chaos in a duality with order, as a means to better understand order, found earlier expression in the mathematical worldview of native North American peoples. Such sophisticated and seemingly contradictory mathematics was seen as intuitively obvious for centuries by American Indians.

Summary and Implications for Teaching and Learning Mathematics

In this ethnomathematical review, the authors have presented ideas drawn from the culture of North American Indians, as well as their relation to traditional Western mathematics. Beginning with a presentation of the cultural context from which some of the mathematics developed (a group culture of hunting, gathering and some farming), the article went on to focus on specific representative mathematics topics of significance to

Indian culture: numeration, geometry, measurement, probability and chance, and chaos theory. It was further offered that elements of current topics in modern mathematics, such as chaos theory and the related discipline of fractal geometry, also are evidenced in traditional Indian mathematics.

While in and of themselves these ideas should be of interest to any mathematician, they have additional relevance to today's public school teachers and students. Classrooms are increasingly composed of students from diverse backgrounds including, especially in the West, American Indian students. These students come from a rich cultural heritage, the mathematical component of which may be unknown to them and, quite likely, to non-Indian students. The explorations, research and activities in American Indian mathematics presented in this paper may not only allow Indian students to be more active participants in, and contributors to, their mathematics classes, but also may foster further understanding by all students of Native cultures and their contributions to society at large. This presentation also may encourage students to further investigate other areas of American Indian mathematics and thereby attain a deeper understanding of mathematics itself.

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Table 1

Numbers with Zuni Number Words and Literal Meanings

Number	Number Words	Literal Meaning
1	topinte	"taken to start with"
2	kwilli	"that put down with its like"
3	hai	"equally dividing one"
4	awite	"all but done with"
5	opte	"the cut off"
6	topalikya	"another brought to add with"
7	kwillikikya	"two brought to add with"
8	hailikya	"three brought to add with"
9	tenalikya	"all but all are brought to add with"
10	astemthla	"all of the fingers"

Table 2

Shape Category: Round

Ojibway Word	Sample Objects
noomin	cucumber, long potato, egg, ...
wewemi-noomin	medicine wheel, hoop, spherical stone, ...

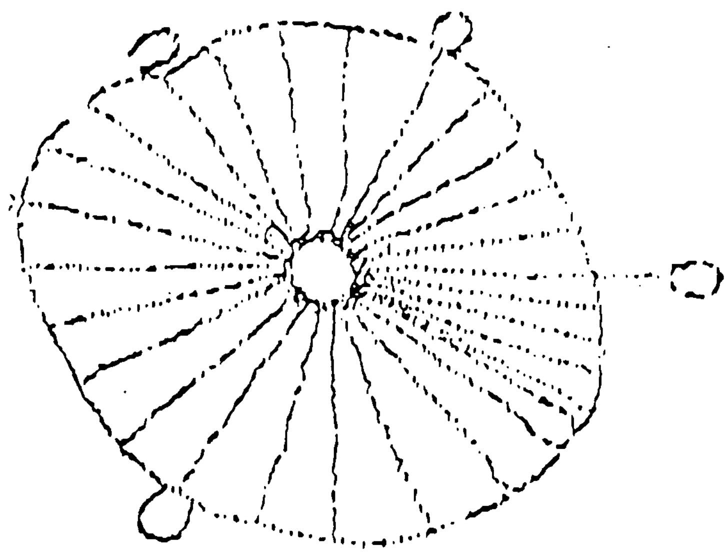
Table 3

Comparison of Western and Indian Dimensionality

Dimensionality	Western Characteristic	Example	Indian Dimensional Characteristic	Example
1-D	Length	Line	Large length, small width and thickness	Stick
2-D	Length and width	Plane	Large length and width, small thickness	Animal skin
3-D	Length, width and depth	Solid	Large length, width and thickness	Acorn

Figure 1

Schematic Representation of Big Horn Medicine Wheel



(Adapted from Geist, 1993.)

Figure 2

Elements of Mayan Numeration System

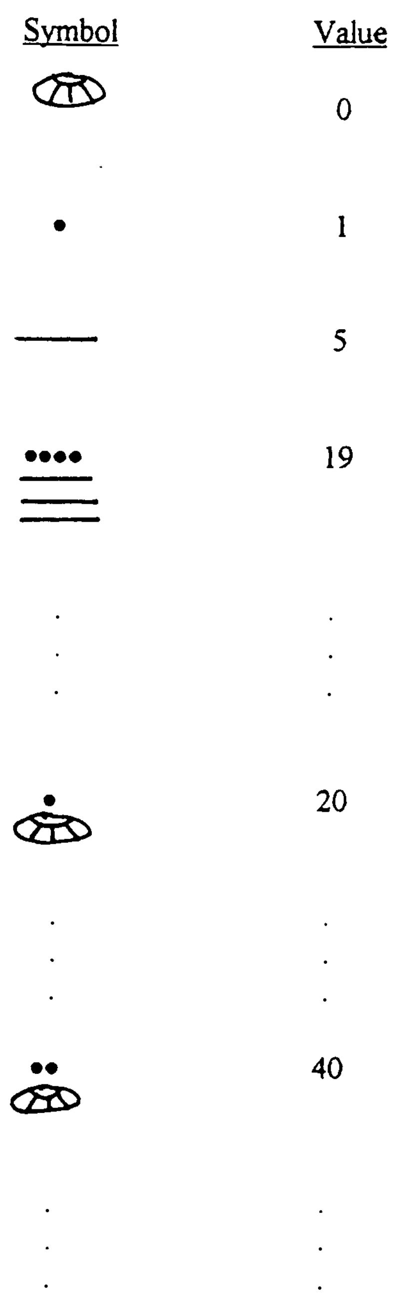
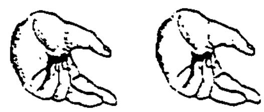


Figure 3

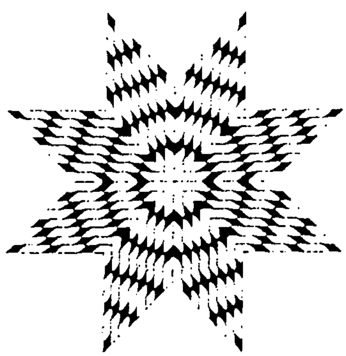
Inuit Method of Counting to 100

Number	Inuit Representation
10	
15	
20	
100	

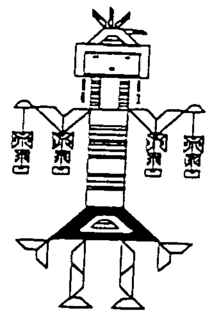
(Adapted from Closs, 1986.)

Figure 4

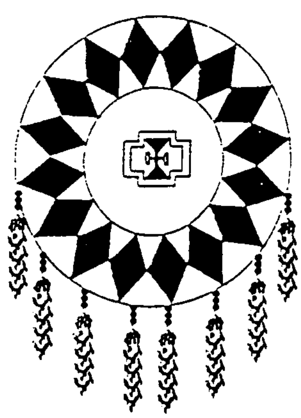
Geometry Patterns in Native American Arts and Crafts



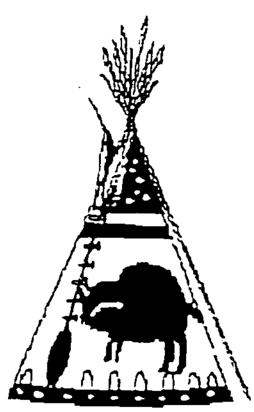
a) Assiniboine quilt pattern



b) Navajo sandpainting design



c) Cheyenne medicine wheel



d) Blackfeet tipi design

(Adapted from Lott & Burke, 1998.)

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